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Rural Domestic Well-Water Quality in the Sand Hills

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Rural Domestic Well-water Quality in the *Sand Hills*

Groundwater Region 1 from *Domestic Water-well Quality in Rural Nebraska*
(A data-analysis report for the Nebraska Department of Health compiled by D. C. Gosselin and others, 1996)

Geology and Hydrogeology

Groundwater Region 1 occupies the Sand Hills area (Figure 1). The geology and groundwater resources have been described by Diffendal (1982), Bleed (1989), and Swinehart and Diffendal (1989). Except where indicated, the following hydrogeology is taken from these sources. The base of the principal groundwater-bearing units is generally the bottom of the Tertiary Ogallala Group. In the western Sand Hills, the Ogallala Group is underlain by Tertiary Arikaree and White River groups, consisting dominantly of fine-grained sediments deposited by wind (eolian) or rivers (alluvial); in the eastern Sand Hills, it is underlain by the Cretaceous Pierre Shale. Beneath the Sand Hills, the Ogallala consists mostly of fine- to medium-grained sand deposited in river environments. Interlayered with that sand are lesser amounts of siltstone, volcanic ash, and local occurrences of coarse sand and gravel. Because of its complex history of deposition and erosion, the Ogallala ranges in thickness from 100 to 800 feet. The next younger materials are river-deposited sediments--the Broadwater and Long Pine formations. These deposits have a maximum thickness of 300 feet, but average about 50 feet. After a long period of significant modification of the land surface by wind, rivers, and soil formation, wind-blown silts (loess) were deposited in the easternmost part of the Sand Hills. Following this, the deposition of sand dunes occurred. These dunes consist primarily of fine-grained, moderately well-sorted sand. (Geologic cross-sections for Region 1 are available at the Conservation and Survey Division; Figure 1.)

The Ogallala Group, the Broadwater and Long Pine formations, and the dune sands are the primary sources of groundwater (Table 1). These units are part of the High Plains aquifer that extends from South Dakota to Texas, underlying parts of eight states, as defined by the U.S. Geological Survey (Gutentag and Weeks, 1980; Weeks and Gutentag, 1981). The term *High Plains aquifer* is preferred to the *Ogallala aquifer* because Ogallala rocks constitute only one part of this groundwater system. The type, distribution, and thickness of these deposits, in conjunction with the relatively permeable dune sand, has resulted in a plentiful groundwater resource. The thickness of the groundwater system ranges from 200 to about 900 feet. Depth to water depends on position in the landscape; it may be 300 feet or greater under the top of a dune, but it may be 100 feet or less under a dry interdunal valley or at or near the surface in valleys where groundwater discharges into lakes, marshes, or subirrigated meadows. The natural quality of the groundwater is good; total dissolved solids (TDS) generally are less than 200 parts per million (ppm).

Results*

Well Characteristics

Characteristics of the wells sampled during the 1994-1995 study are summarized in Table GW1.1. The average year of installation was 1970; more than 60 percent of the wells were installed between 1960 and 1979. The oldest well was installed in 1925. Available information indicates that 88 percent of the wells were drilled and constructed of predominantly PVC or steel casing. The majority have sanitary seals. Nearly 45 percent of the wells have depths between 100 and 199 feet. The depth averaged 129 feet and ranged from 10 to 400 feet. For the 174 wells for which information is available, the average well diameter is 5 inches; the minimum is 1 inch and the maximum, 36 inches. Each well is used by an average of 3.5 individuals. Regarding agricultural chemicals used on the premises, nitrate was used at more than half (53 percent) of the sites and pesticides were used on slightly less than half.

**** Where associations, relationships, increases or decreases are discussed, our analyses have determined that they are statistically significant. If the relationship between contaminant concentrations and various factors are not discussed, they have not been demonstrated to be statistically significant.***

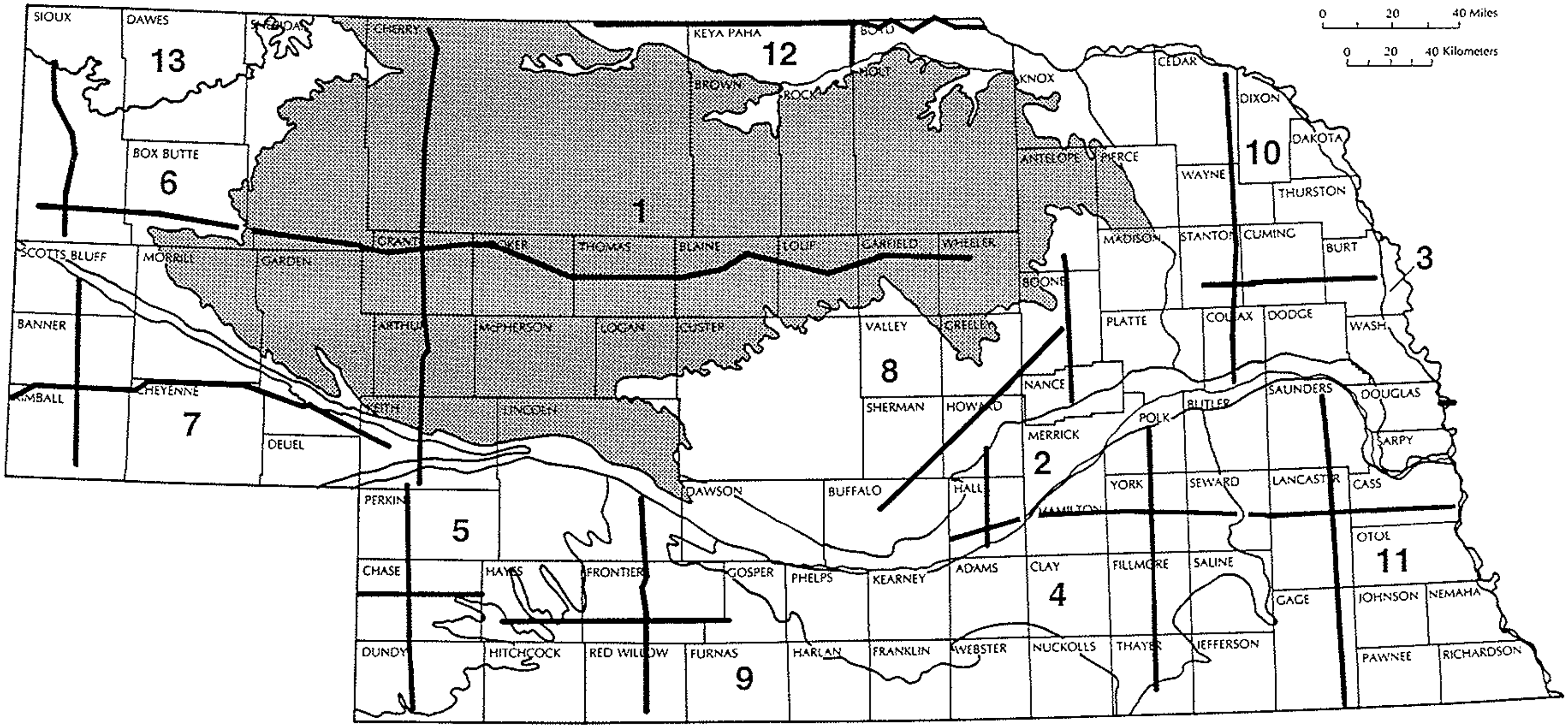


Fig. 1—*Locations of geologic cross sections* **(Region 1 in gray)**

Water-bearing Properties of Major Rock Units in Nebraska

From *The Groundwater Atlas of Nebraska* — Conservation and Survey Division, University of Nebraska-Lincoln

Era	Period	Epoch	Millions of years	Group or Formation	Lithology	Water-bearing Properties
Cenozoic	Quaternary	Holocene			Sand, silt, gravel and clay	Principal groundwater reservoir; Ogallala is absent in east and northwest. Arikaree is present primarily in west.
		Pleistocene	0.01			
		Pliocene	~2.0		Sand, gravel and silt	
		Miocene	5	Ogallala	Sand, sandstone, siltstone and some gravel	
		Oligocene	24	Arikaree	Sandstone and siltstone	
				White River	Siltstone, sandstone and clay in lower part	Secondary aquifer in west; water may be highly mineralized.
		Eocene	37	Rocks of this age are not identified in Nebraska.		
		Paleocene	58			
Mesozoic	Cretaceous	Late Cretaceous	67	Lance	Sandstone and siltstone	Generally not an aquifer; yields water to few wells in west.
				Fox Hills		
				Pierre	Shale and some sandstone in west	Generally not an aquifer; sandstones in west yield highly mineralized water to few industrial wells.
				Niobrara	Shaly chalk and limestone	Secondary aquifer where fractured and at shallow depths, primarily in east.
				Carlile	Shale; in some areas contains sandstones in upper part	Generally not an aquifer; sandstones yield water to few wells in northeast.
				Greenhorn-Graneros	Limestone and shale	Generally not an aquifer, yields water to few wells in east.
		Early Cretaceous	98	Dakota	Sandstone and shale	Secondary aquifer, primarily in east; water may be highly mineralized.
	Jurassic		144		Siltstone and some sandstone	Not an aquifer
	Triassic		208		Siltstone	Not an aquifer
Paleozoic	Permian		245		Limestone, dolomites, shales and sandstone.	Some sandstone, limestone and dolomites are secondary aquifers in east. Water may be highly mineralized.
	Pennsylvanian		286			
	Mississippian		320			
	Devonian		360			
	Silurian		408			
	Ordovician		438			
	Cambrian		505			
Precambrian			570			

Table 1—Hydrostratigraphic chart (showing water-bearing rock units) of Nebraska
Time divisions are not to scale.

Table GW1.1. Summary of Domestic Well Characteristics and Water Quality Data (1994-95)

Well characteristics

		Number of wells	Mean	Minimum	Maximum	Standard deviation
Well Installation Date						
	All	240	1970	1925	1988	12
	<1940	7				
	1940-1969	29				
	1960-1979	146				
	1980-present	58				
Well Depth (feet)						
	All	234	129	10	400	72
	<50	24				
	50-99	60				
	100-199	104				
	>200	46				
Well Diameter (inches)						
	All	174	5.3	1	36	3.0
	<2	4				
	2-3	2				
	4-5	118				
	6-7	19				
	>8	31				
Number of Well Users		181	3.5	0	8	1.8
Distance to Contaminant Source (feet):						
	cesspool	29	125	5	400	95
	septic	250	119	2	510	99
	waste lagoon	5	830	150	2600	1002
	barnyard	220	236	0	2600	327
	pasture land	169	371	0	4300	495
	cropland	112	898	20	7800	1081
Well Type:						
	drilled	237				
	driven	25				
	dug	1				
	other	2				
Casing Material:						
	steel	44				
	plastic	172				
	concrete	1				
	brick	0				
	tile	0				
	other	0				
Sanitary Seal:						
	yes	205				
	no	34				
Casing in Pit:						
	yes	70				
	no	190				
Nitrate Used:						
	yes	136				
	no	121				
Pesticide Used:						
	yes	131				
	no	133				

Water Quality Data

		Number of wells	Mean	Median	Minimum	Maximum	Standard deviation	Detections
Nitrate as Nitrogen (ppm NO3-N)								
1994-1995		278	4.5	1.2	0.1	78.1	9.4	
Bacteria (colonies per 100 ml)								
1994-1995		217			0	100		25
Pesticides (ppb)								
1994-1995								
	Atrazine	279			0	0		0

Nitrates

Nitrate data for the 278 wells sampled during the 1994-1995 study are summarized in Table GW1.1. Their locations are given in Figure GW1.1. The nitrate-nitrogen concentrations ranged from less than 0.1 ppm to a maximum of 78.1 ppm. More than 72 percent of the samples had concentrations less than 3 ppm, indicating that 28 percent have been affected by nitrate contamination. Slightly more than 12 percent exceeded the 10 ppm maximum contaminant level (mcl). The average value for all samples is 4.5 ppm, and the median value is 1.2.

The Wilcoxon Signed Rank Test reveals a general increase in nitrate-nitrogen concentrations among the 216 wells that had different concentrations between the 1985-1989 and 1994-1995 sampling periods. This general increase is reflected in Figure GW1.2. The number of wells with concentrations in the 3-to-4.9 ppm range has decreased 3.5 percent and the number of wells with concentrations greater than 10 ppm has increased 3 percent.

The factors that may influence the nitrate-nitrogen concentrations in rural domestic wells are divided into three groups: 1) well-construction factors: casing type, age, diameter, well completed in or out of pit, sanitary seal, and well type; 2) distance factors: distance to cesspool, septic systems, waste lagoons, barnyards, pasture, and cropland; and 3) hydrogeologic and site factors: well depth, depth to water, landscape and soil characteristics (Figure GW1.1), and agricultural chemical use.

Well-construction factors

Application of the Mann-Whitney Rank Sum Test indicated no statistical differences in nitrate-nitrogen concentrations associated with any of the following well-construction groups: casing type (steel or PVC), sanitary seal (yes or no), casing completion (in or out of pit), and well type (drilled or driven). Neither the Spearman Rank Order Correlation or Kruskal-Wallis Test demonstrated any relationships between nitrate-nitrogen concentrations and installation date (age) and diameter.

Distance factors

The association of nitrate-nitrogen concentrations and the distance factors was examined using the Spearman Rank Order Correlation Test, which indicated a significant association between higher nitrate-nitrogen concentrations and decreasing distance to cropland.

Hydrogeology and site factors

The Mann-Whitney Test indicates that wells where nitrogen fertilizer was used on the premises have generally higher nitrate concentrations than wells where nitrogen was not used. The Spearman Rank Order Correlation Test indicated no statistical association between well depth or water table and nitrate-nitrogen concentrations. However, considering only those wells with nitrate-nitrogen concentrations greater than 3 ppm (that is, contaminated), the Spearman test indicated a statistically significant association of higher nitrate-nitrogen concentrations and shallower well depths.

The relationship between nitrate-nitrogen concentration and the landscape and soil characteristics indicated that about 92 percent of the wells are located in two soil classes: class 1 (23 percent; sandy-level) and class 2 (69 percent; sandy-sloping) (Figure. GW1.1). The Chi-Square Test and Fisher Exact Test indicated that wells in sandy-sloping soils had a greater likelihood of having nitrate-nitrogen concentrations greater than 5 ppm.

Pesticides

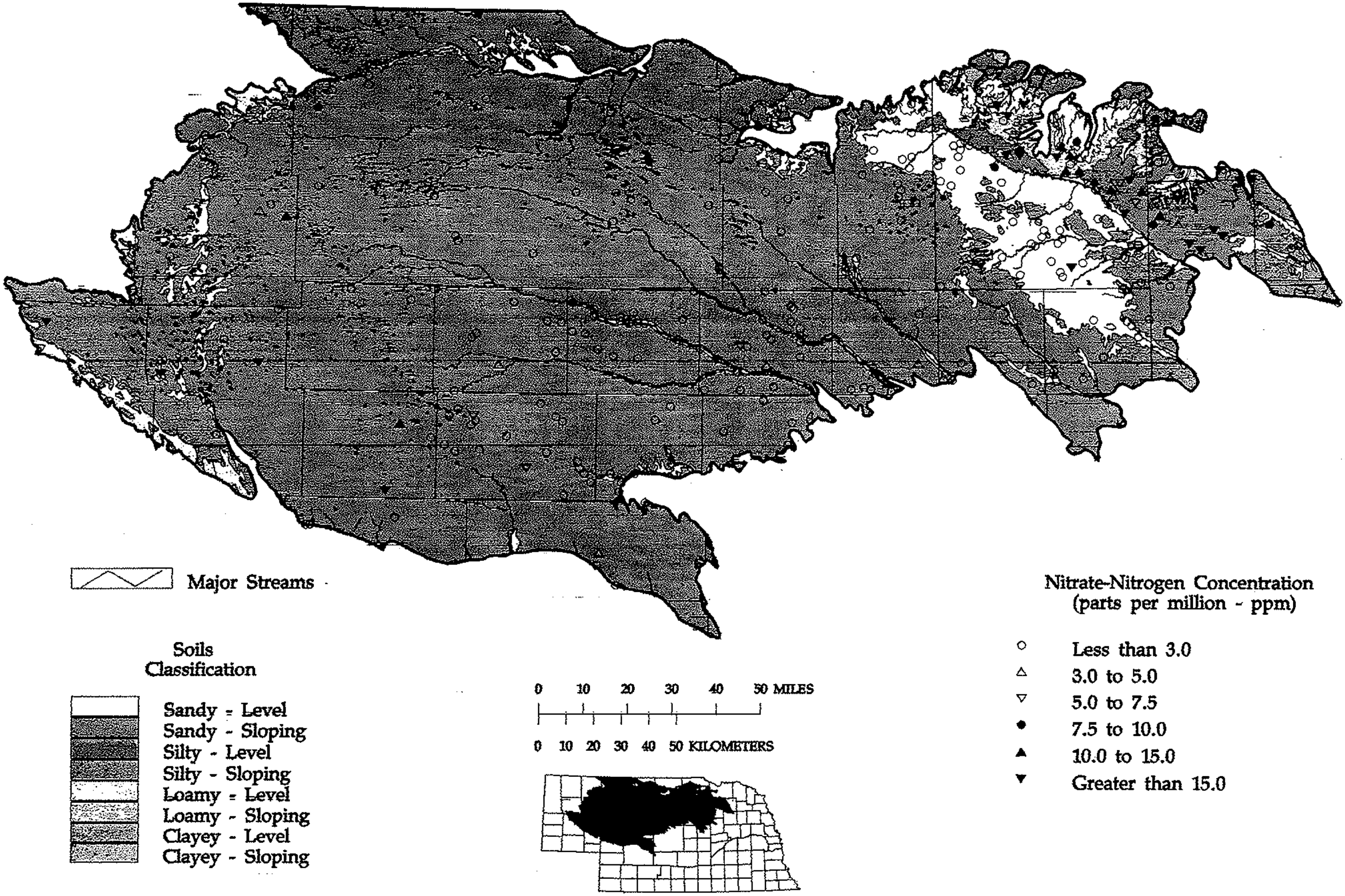
There were no detections of pesticides in the 279 wells analyzed (Figure GW1.3).

Bacteria

Data on coliform bacteria for the 217 wells sampled during the 1994-1995 study are summarized in Table GW1.1, and their locations are shown in Figure GW1.4. Bacteria data expressed in colonies per 100 ml of water ranged from 0 to greater than 100. More than 88 percent of the samples had no detectable coliform bacteria, indicating less than 12 percent of the wells have been affected by bacterial contamination and exceed the mcl for bacteria.

The Wilcoxon Signed Rank Test indicated no statistical difference between the 1994-1995 and 1985-1989 bacteria data. The Spearman test indicated that there is no statistical association between bacterial contamination

Nebraska Department of Health
Rural Domestic Well Water Quality Study: 1994-1995
Nitrate Sampling Locations - Groundwater Region #1



Groundwater Region #1

Figure GW1.1

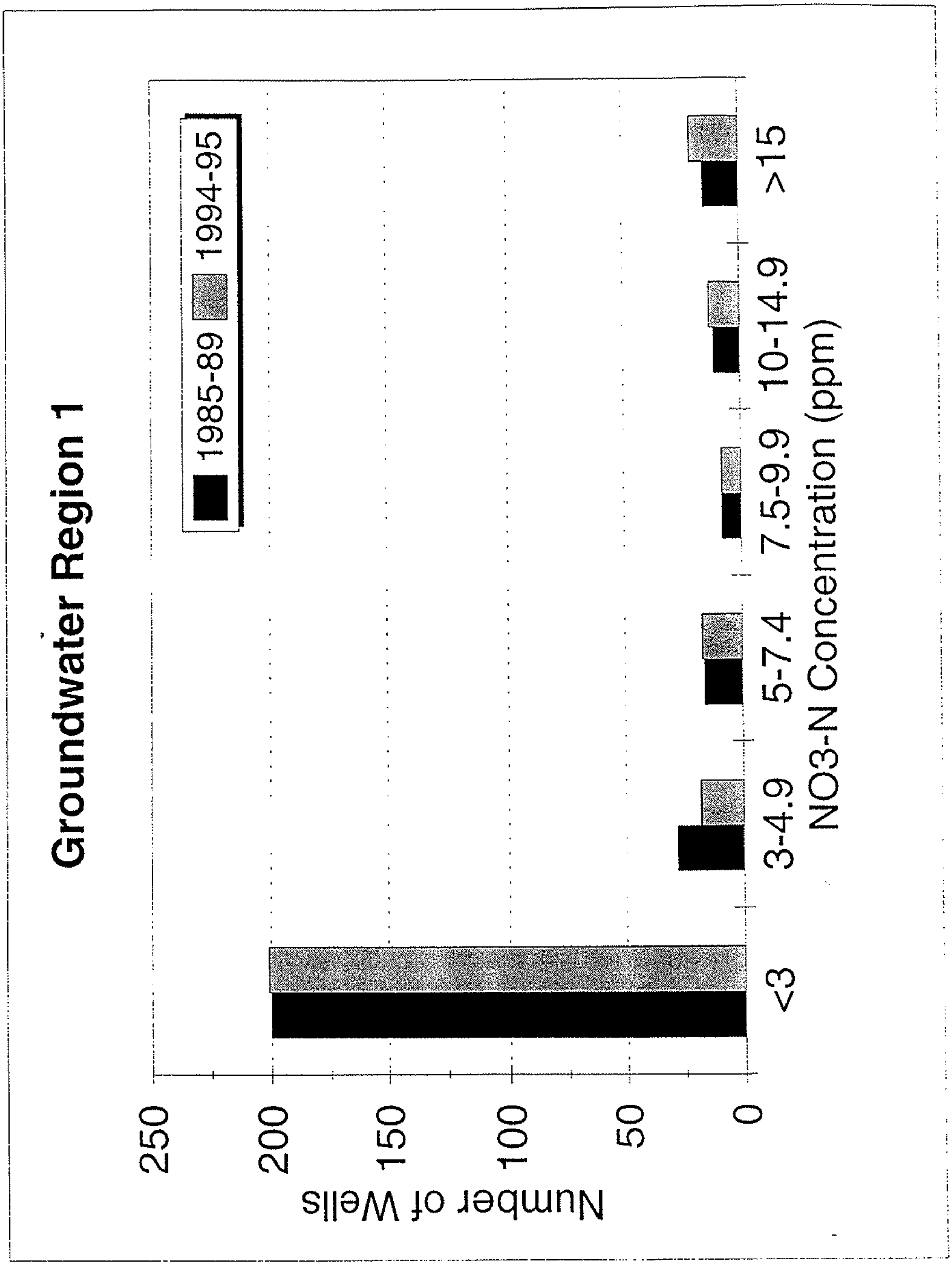

Groundwater Region 1
1985-89
1994-95
Number of Wells
250
200
150
100
50
0
<3
3-4.9
5-7.4
7.5-9.9
10-14.9
>15
NO3-N Concentration (ppm)

Figure GW1.2

Nebraska Department of Health
Rural Domestic Well Water Quality Study: 1994-1995
Pesticide Sampling Locations - Groundwater Region #1

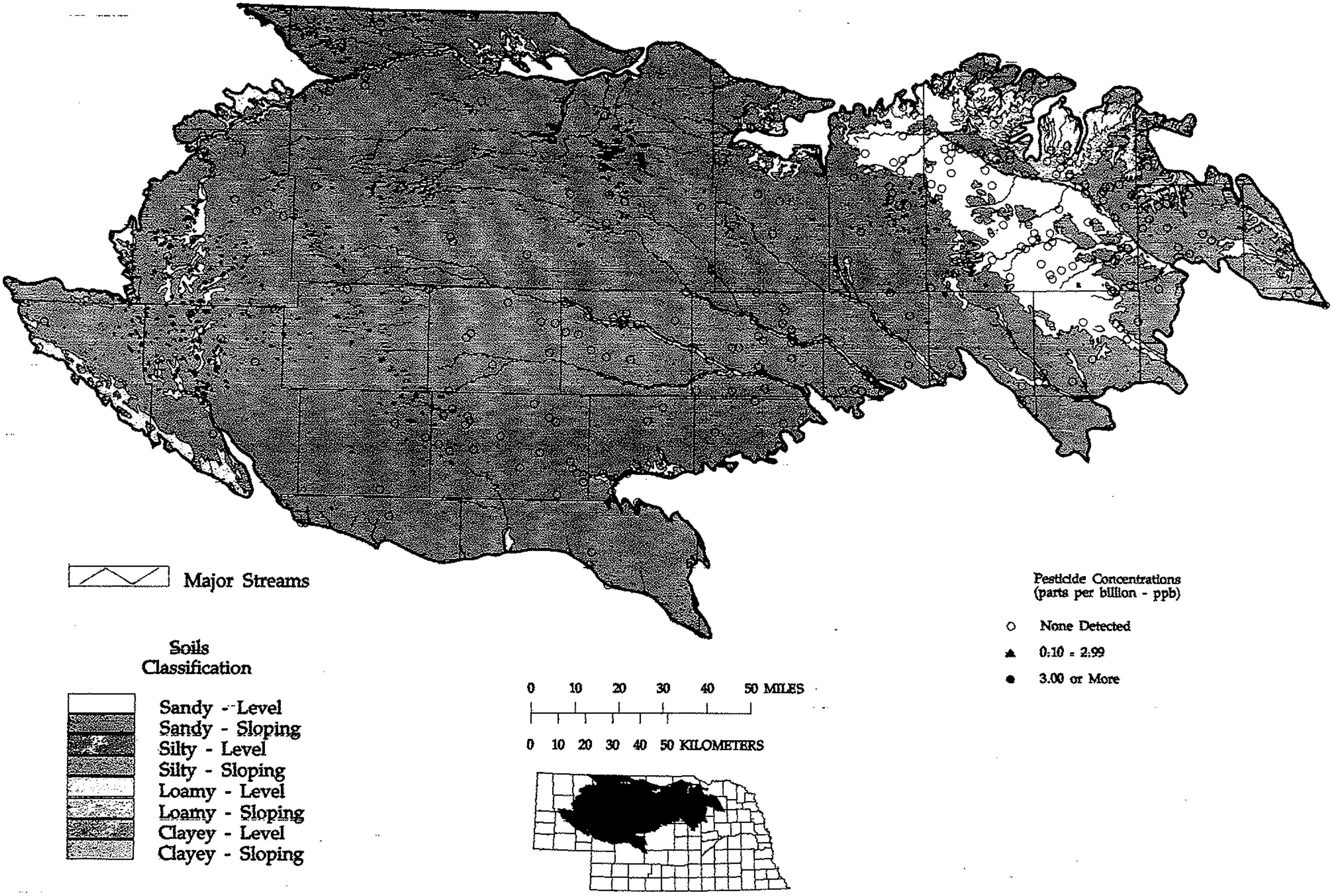


Figure GW1.3

Nebraska Department of Health
Rural Domestic Well Water Quality Study: 1994-1995
Bacteria Sampling Locations - Groundwater Region #1

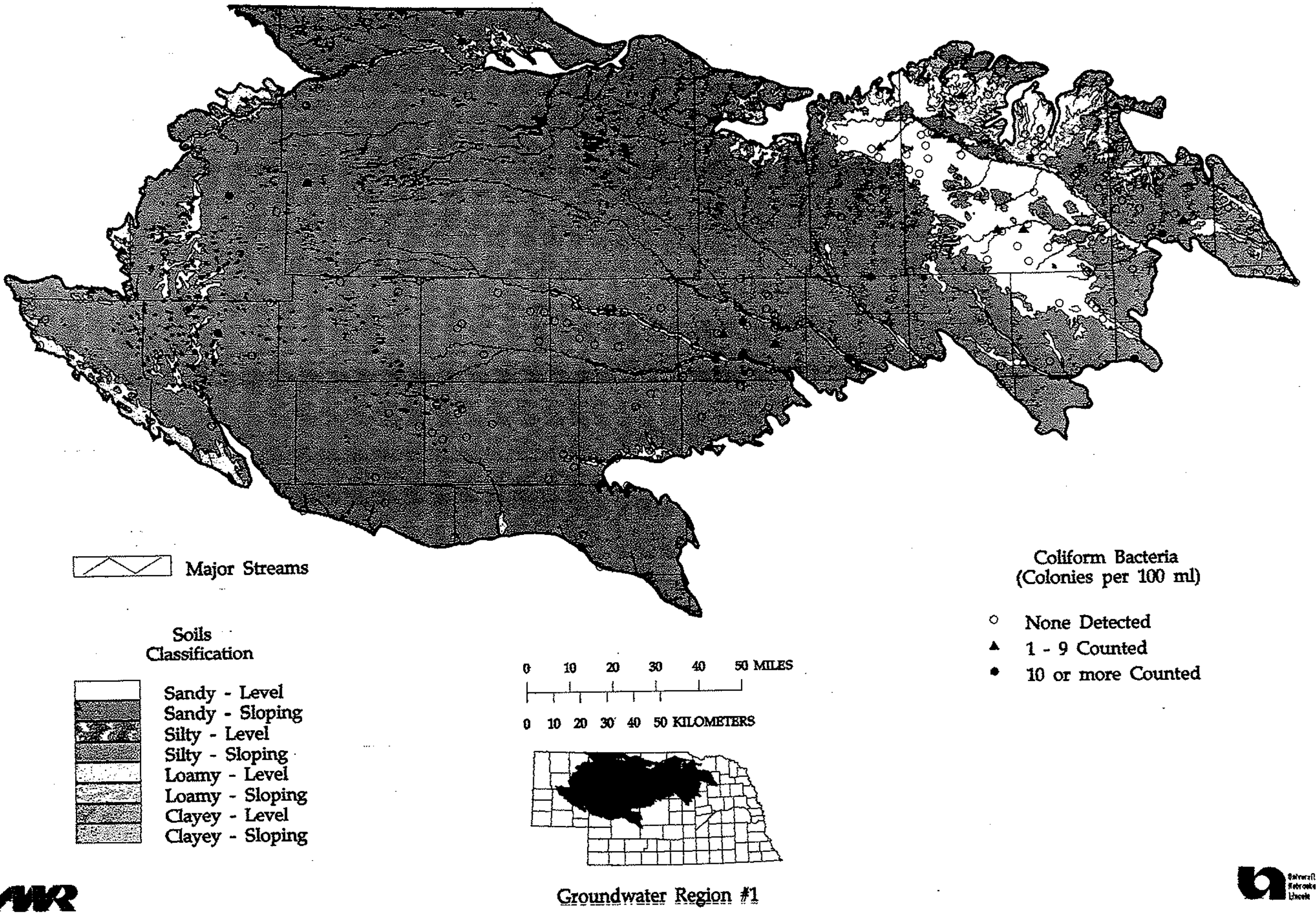


Figure GW1.4

and nitrate or distance factors. In fact, nitrate-nitrogen concentrations only exceeded 10 ppm in four of the wells contaminated by bacteria.

Of the wells having bacteria contamination, 50 percent of wells for which information is available have depths less than 100 feet. Although there is no statistical association of bacteria and distances to septic systems or barnyards, six and eight wells, respectively, did not meet the regulatory distance criteria of 50 and 100 feet, respectively, for these potential point sources.

Discussion

Our analyses indicated the following statistically significant associations: 1) higher nitrate-nitrogen concentrations are associated with nitrogen use on the premises and decreasing distances to cropland; 2) for wells with nitrate-nitrogen greater than 3 ppm, higher concentrations are associated with wells having shallower depths; and 3) wells located in sandy-sloping soils had a greater tendency to have higher nitrate-nitrogen concentrations than wells in sandy-level soils. Well construction did not necessarily affect the concentration of nitrate-nitrogen in individual wells. A notable exception to this conclusion may be a 36-inch diameter, concrete-cased well installed in 1977 that was 60 feet deep and 25 feet from a barnyard. The high nitrate-nitrogen concentrations of 12 and 14 ppm in 1985-1989 and 1994-1995, respectively, strongly indicate that improving the siting of this well could have helped prevent contamination.

An examination of Figure GW1.1 indicates that wells with more than 10 ppm are most common in the northeastern part of the region. Nearly 77 percent are in Antelope, Knox, or Holt counties. The average depth of these wells is about 115 feet. Sixty-two percent of these wells are in Holt County in an area known as "the Holt Table." This area has been recognized previously for its high incidence of groundwater contamination (Engberg, 1971; Exner and Spalding, 1979; Spalding and Exner, 1991; Lackey, 1996). The remaining parts of the region apparently have minimal amounts of contamination. The association of higher nitrate concentrations with nitrogen use on the premises and decreasing distances to cropland clearly reflects the irrigated agricultural area of the Holt Table. The stronger association of higher nitrates with sandy-sloping soils also reflects the influence of the Holt Table area where this is the dominant soil type. Although Holt, Knox, and Antelope counties are included in the Sand Hills region, the incidence of contamination and land-use characteristics indicate that they should be included in groundwater region 8 or 12.

Although the association of increasing nitrate concentrations with decreasing well depth, especially those significantly affected by contamination, has been observed in many other locations, it does support the general contention that the deeper the well, the less likely it will be affected by contamination. During well installation, especially on the Holt Table, extending the well far below the water table should be encouraged to minimize the long-term impact of contamination.

Lack of an association of nitrate and bacteria with distance factors, often related to point sources, indicates that these sources have not contributed significantly to variations in the concentration of nitrate-nitrogen in individual wells. However, distance between a well and a point source of contamination is only one of the factors that determines whether a well will become contaminated. Other factors are the spatial relationship of the well to the point source; that is, whether the well is near or far, upgradient, downgradient, or sitting laterally from the point source. Furthermore, another important factor is whether the groundwater-bearing units have similar properties. The groundwater-bearing units include stratigraphic layers that affect the direction and rate of local groundwater movement.

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